PATENT ABSTRACTS OF JAPAN

(11)Publication number : 06-347529

(43)Date of publication of application : 22.12.1994

(51)Int.Cl. G01S 3/14

(21)Application number : 05-135996

(22)Date of filing : 07.06.1993

(71)Applicant : NEC CORP

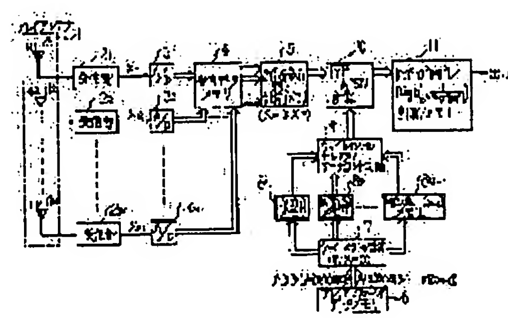
(72)Inventor : TANAKA MOTOYASU
ATOKAWA AKIHISA
TERASAWA NOBUO

(54) METHOD AND DEVICE FOR MEASURING BEARING

(57)Abstract:

PURPOSE: To resolve and measure the bearing of interference wave including a coherent signal (also called as a multi-path signal), in which arrival wave are correlated with each other completely at the same frequency, by an array antenna having optional array elements and arrangement.

CONSTITUTION: The device is provided with an A/D converter 3 which divides receiving signals, that are received by an array antenna consisting of M pieces of array element, into real and imaginary parts to convert them into receiving data, a circuit 5 to find out a covariance matrix from the receiving data, and a circuit 11 to calculate an evaluation function relevant to inner noise in connection with the covariance matrix and array manifold, and it detects the combination of arrival bearings by which the evaluation function is minimized.



LEGAL STATUS

[Date of request for examination] 07.06.1993

[Date of sending the examiner's decision of rejection]	
[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]	
[Date of final disposal for application]	
[Patent number]	2630200
[Date of registration]	18.04.1997
[Number of appeal against examiner's decision of rejection]	
[Date of requesting appeal against examiner's decision of rejection]	
[Date of extinction of right]	

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the bearing measuring method equipment using the super RIZORYUSHON (superresolution) technique which decomposes and measures bearing of an interference wave where two or more incoming waves exist in the same frequency, and its equipment.
[0002]
[Description of the Prior Art] Bearing of an interference wave where two or more incoming waves exist in the same frequency was decomposed using the array component of arbitration, and the array antennas of an array array, and since the method of MUSIC (MUltiple SIgnal Classification) is very efficient as a ****** super RIZORYUSHON technique, it came to be put in practical use in recent years. The method of MUSIC was also called the "characteristic value part solution method" or "characteristic vector method", it was announced by 1981R.O.Schmidt, and research of relation has been made by the researcher of after that many. the following -- R. "O.Schmidt, MultipleEmitter Locaticn and Signal Parameter Estimation" (it is called IEEE TRANSACTION ON ANTENNA AND PROPAGATION, VOL.AP-34.NO, 3PP.276-280, MARCH 1986, and the following reference 1) -- reference -- carrying out -- MUSIC -- the bearing measuring method by law is explained.
[0003] The input signal received with the array antennas which consist of M array components serves as line type association with the input signal (an arrival fraction is assumed to be D) of D individual, and the internal noise of a receiver. It is as follows when this is expressed in procession.
[0004]

$$\begin{bmatrix} X_1 \\ X_2 \\ X_M \end{bmatrix} = \begin{bmatrix} a(\theta_1)\ a(\theta_2) \cdots a(\theta_D) \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_D \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_M \end{bmatrix}$$

$$X = AF + N \qquad \cdots (1)$$

[0005] It is vector X=(X1 X2 -- XM) T here. They are M input signals (complex). Moreover, matrix A= (a(theta 1) a (theta 2) -- [a (thetaD) is called an array manifold (array manifold), and the column vector a(theta) =(a1 thetaa2 theta--aM theta) T is the response (complex) of the array antennas to Bearing theta, and is called a mode vector or a steering vector.]) When the linear independence of a (theta) is guaranteed at 0 degree < theta<360 degrees, it is equivalent to the ability of Bearing theta to be found that a (theta) can be found. Vector F=(F1 F2 -- FD) T It is the

input signal (complex) of D individual. Vector N=(N1 N2 -- NM) T It is the internal noise (henceforth a noise) of M receivers, and assumes [having not correlated mutually and]. Moreover, since it is easy, all of M noise power are sigma2 equally. It carries out and it is assumed by prior measurement etc. that it is known. Namely, [0006]

$$\overline{|N_1|^2} = \overline{|N_2|^2} = \cdots\cdots \overline{|N_M|^2} = \sigma^2 \text{（既知）}$$

[0007] ** -- although assumed -- this assumption -- generality -- ****** -- it is not a thing. T expresses the transpose of a matrix and a bar expresses the average here. Next, it is [0008] when the covariance matrix (covariance matrix) of (1) type is set to S.

$$S = \overline{XX^H} = A\overline{FF^H}A^H + \overline{NN^H}$$

[0009] A next door, [0010]

$$S = APA^H + \sigma^2 I \qquad \text{--- (2)}$$

[0011] It is expressed. However, H expressed complex-conjugate transposition and assumes [having not correlated and] the input signal and the noise. Moreover, [0012]

$$P = \overline{FF^H} \qquad \text{--- (3)}$$

[0013] It is called a ****** matrix of correlation or the power matrix (power matrix) of an input signal, and becomes a positive-definite value (positive delinite). I is a unit matrix. Since the rank (rank: rank) of the signal matrix of correlation P will serve as D supposing it supposes that D<M, i.e., the number of input signals, is smaller than several M of an array component here and there is no perfect correlation between input signals, it is APAH. A rank also serves as D. It is [0014] when the characteristic value of M pieces of a covariance matrix S is arranged in order of magnitude at this time.

$$\underbrace{\lambda_1, \lambda_2, \cdots\cdots, \lambda_D}_{\text{入力信号の固有値}}, \underbrace{\lambda_{D+1}, \cdots\cdots, \lambda_M}_{\text{雑音の固有値}} \qquad \text{---- (4)}$$

[0015] It becomes and is [0016] further.

$$\lambda_{D+1} = \lambda_{D+2} = \cdots\cdots = \lambda_M = \sigma^2 \text{（最小固有値）} \qquad \text{--- (5)}$$

[0017] It becomes. Moreover, characteristic vector E corresponding to such characteristic value is [0018].

$$\left.\begin{aligned} E &= (E_S E_N) \\ E_S &= (E_1 E_2 \cdots\cdots E_D) \\ E_N &= (E_{D+1} E_{D+2} \cdots\cdots E_M) \end{aligned}\right] \text{(6)}$$

[0019] It becomes. However, ES lambda 1 - lambdaD The signal subspace of the measuring line type space E is stretched by the corresponding signal-space characteristic vector, and it is EN. lambdaD+1 - lambdaM The noise subspace of E is stretched by the corresponding noise space characteristic vector. Moreover, ES EN It is in orthogonality relation (EN is the orthocomplement of ES).

[0020]

$$E = E_S \dotplus E_N \quad (\dotplus : 直和(\text{direct sum})) \qquad \text{--- (7)}$$

[0021] It becomes. This is based on the following reasons. Characteristic vector E SE=lambdaE (8)
It ****** and is especially lambda=sigma 2. At the time SEN =sigma2 EN (9)
It is [0022] when a next door and (2) types are substituted for (9) types.

$$(APA^H + \sigma^2 I) E_N = \sigma^2 E_N$$

$$APA^H E_N = 0$$

$$E_N^H APA^H E_N = (A^H E_N)^H P (A^H E_N) = 0 \qquad \text{--- (10)}$$

[0023] It becomes. (10) Set at a ceremony and the ** matrix A is a full rank (that all bearings of an incoming wave differ, and equivalence).
** Matrix P (positive-definite value) is a full rank (that there is no perfect correlation between input signals, and equivalence).
In the ** case AH EN =0 (11)
Since it is an array manifold (set of the mode vector of the incoming wave of D individual), a next door and Matrix A are the signal subspace ES. It belongs and is ES. EN It intersects perpendicularly. Therefore, characteristic vector [as opposed to / decompose the characteristic value of a covariance matrix S and / the minimum characteristic value] EN It asks and they are the mode vectors a (theta) and EN. The inverse number of the square of Euclidean distance
[0024]

$$\frac{1}{a^H(\theta) E_N E_N^H a(\theta)} \qquad \text{--- (12)}$$

[0025] If consider a performance index, and take out the mode vector a of a certain bearing theta (theta), theta is changed over 0 degree - 360 degrees out of all 0<theta<360-degree array manifolds, (12) types are calculated and a peak (peak) is searched for, bearing of the interference wave of D individual can be decomposed and presumed. In addition, in displaying, when it takes the logarithm of (12) types, since it is convenient, it is [0026].

$$10 \log_{10} \left(\frac{1}{a^H(\theta) E_N E_N^H a(\theta)} \right)$$

[0027] ****** may be performed.
[0028] The configuration of the conventional example explained above is shown in drawing 2 . The signal received in two or more array antennas 1 (11 -1M) and receive sections (21 -2M) by drawing 2 is changed into the digital data of real part and imaginary part with A/D converter 3 (31-3M), and is stored in the receiving data memory 4. The received data read from memory 4 are sent to covariance-matrix count / memory circuit 5, and a covariance matrix S is called for. The characteristic value / characteristic vector count / memory circuit 12 which receives this process (4), (5), (6), and (7) types, and asks for a characteristic vector. This output is sent to the circuit 14 which asks for (12) evaluation-of-expression function, and the performance index for bearing measurement is searched for.
[0029]
[Problem(s) to be Solved by the Invention] MUSIC by the reference 1 mentioned above -- there are the following troubles in law. That is, when it includes the coherent signal (or multi-pass signal) which has perfect correlation in the part between the input signals of D individual, the rank of the signal matrix of correlation P becomes smaller than D, and it becomes impossible to

decompose the characteristic value of the input signal of a covariance matrix S into D individual therefore, and it is the signal-space characteristic vector ES. And ES Noise space characteristic vector EN which has the relation of orthocomplement Asking correctly becomes impossible. Even if (11) types stop realizing and calculate (12) types, it becomes impossible therefore, to presume bearing of an incoming wave at this time. As an approach improved so that bearing of an interference wave including such a coherent signal might be decomposed and bearing could be presumed correctly, there is an approach of "tooth-space SHARU smoothing (Spatial Smoothing)." this approach -- MUSIC of drawing 2 -- in the example of law, when array antennas 1 are made into a regular-intervals linear array, application in the case where a coherent signal is included is enabled. "**** Tie-Jum shan and Mazi Wax, AND Thomas Kajlath and On Spatial Smoothing for Direction of-Arrival Estimation of Coherent Signals" () [IEEE TRANSACTION] ON Acastcs, SPEECH, AND SIGNAL PROCESING, VOL.ASSP-33, NO.4, pp 806-811, AUGUST It depends for calling it 1985 and the following reference 2. However, there is a trouble that the number of incoming waves inapplicable to the array component and array array of (1) arbitration in which (2) presumption is possible becomes M/2 (MUSIC about [in the case of law] 1/2) or less in SUPESHARU smoothing.

[0030]

[Means for Solving the Problem] This invention is for decomposing and presuming bearing of a total input signal between input signals also in the case of an interference wave including a coherent signal with perfect correlation, it can apply to the array component and array array of arbitration, and the number of the maximum presumption incoming waves maintains an individual (M-1) (MUSIC law and the same number). Even if the coherent signal was intermingled in order to take the process which decomposes the characteristic value of a covariance matrix S by the MUSIC method, and asks for a characteristic vector, it diagonalized S when the signal matrix of correlation P stopped having been a full rank, and it calculated characteristic value, since it was no longer what decomposed the input signal correctly, it became presumed impossible.

[0031] Even when it does not take but a coherent signal is intermingled with the following means, the process which this invention asks for characteristic value and a characteristic vector decomposes the arrival bearing of total ******, and makes presumption possible. In this invention, in order to solve a problem, the following wait vectors W are introduced. W=(W1 W2 -- WM) T (13)

The multiplication of the ********** value of W is carried out to an input signal X. If a multiplication result is set to Y Y=WH X (14)

It becomes. Furthermore, it is the square average of Y [0032]

$$\overline{|Y|^2}$$

[0033] It is [0034] when it carries out.

$$\overline{|Y|^2} = \overline{YY^*} = \overline{W^H XX^H W} = W^H \overline{XX^H} W = W^H S W$$

（＊は複素共役を表わす） ---(15)

[0035] It becomes. It is [0036] when (2) types are substituted for (15) types here.

$$\begin{aligned}\overline{|Y|^2} &= W^H (APA^H + \sigma^2 I) W \\ &= W^H APA^H W + \sigma^2 \|W\|^2 \\ &= (A^H W)^H P (A^H W) + \sigma^2 \|W\|^2\end{aligned}$$

ただし‖W‖は Wのノルム(norm)を表わす。

----(16)

[0037] It becomes. Moreover, if (16) types are transformed, the following performance indices can be acquired.

[0038]

$$|Y|^2 - \sigma^2 \|W\|^2 = (A^H W)^H P (A^H W) \quad \cdots (17)$$

[0039] (17) From a formula AH W=0 (18)
the wait vector W with which like fills [****** primary] a formula -- MUSIC from contrast of (11) types -- noise space characteristic vector EN to the minimum characteristic value in law It turns out that it is equivalent. It is EN to calculate the characteristic value of a covariance matrix S in this invention without carrying out. Performance index which solves the simultaneous equation of (18) equations, searches for the equivalent wait vector W directly, and is calculated from a covariance matrix S and the wait vector W ((15) equations and (17) equations)

[0040]

$$|Y|^2 - \sigma^2 \|W\|^2 = W^H S W - \sigma^2 \|W\|^2 \quad \cdots (19)$$

[0041] It is characterized by using and presuming arrival bearing. Therefore, since this invention does not need the full rank conditions of the signal matrix of correlation P, even when a coherent signal is intermingled, it can decompose and presume the arrival bearing of a total input signal. Moreover, it sets at (19) ceremony and the internal-noise power of a receiver is [0042] in a sigma12, sigma22 --, and sigmaM2 and barrack case.

$$\sigma^2 \|W\|^2$$

[0043] It is [0044] to instead of.

$$(\sigma_1^2 |W_1|^2 + \sigma_2^2 |W_2|^2 + \cdots + \sigma_M^2 |W_M|^2)$$

[0045] What is necessary is just to use.

[0046]

[Function] Although the wait vector W searched for from the simultaneous equation of (18) equations in this invention is determined only from the element of the array manifold (theta) A a, i.e., a mode vector, since the arrival fraction D is strange, the number of incoming waves needs to ask for W about each case to 1- (M-1). Namely, [0047]

$$\left.\begin{array}{ll} \text{到来波数が1の場合：} & W(\theta_1) \\ \text{到来波数が2の場合：} & W(\theta_1, \theta_2) \\ \vdots & \vdots \\ \text{到来波数が}(M-1)\text{の場合：} & W(\theta_1, \theta_2, \cdots \theta_{M-1}) \\ & (0^\circ \leq \theta_1, \theta_2, \cdots, \theta_{M-1} < 360^\circ) \end{array}\right\} (20)$$

[0048] Moreover, the reason the number of the maximum presumption incoming waves is set to (M-1) is the array manifold AH. It is because the maximum of D for having a solution effective [the matrix AH W of (18) types] except becoming Dx1 matrix and all the elements of W being set to 0 (zero) since a DxM matrix and the wait vector W are Mx1 matrices is set to (M-1). (20) Since wait ** KUTORU W is the combination (combination) of arrival bearing as shown in a formula, bearing of a total input signal will be presumed to coincidence. For example, when D is (M-1), it is theta 1, theta 2, --thetaM-1. Only when combination is presumed correctly, with regards to the rank of the signal matrix of correlation P, there is nothing and a performance-index (19) type can be made into minimum [0(zero)]. On the contrary, when arrival bearing is able to be investigated in combination [it is called a combination search (combination search) below] and (19) evaluation-of-expression function is able to be made into min, it means that the arrival

bearing (put together) of total input signal was called for.
[0049]
[Example] Next, this invention is explained to **** with reference to a drawing. Drawing 1 is the block diagram showing the configuration of the example of this invention. In drawing 1 , array antennas 1, a receive section 2, the A/D-conversion section 3 that has the function which decomposes an input signal into real part and imaginary part, the receiving data memory 4, the S (covariance matrix) count / memory circuit 5, and the array manifold data memory 6 are provided, and this is as common as the conventional example. That is, the input signal to array antennas 1 to the process of this invention and the MUSIC method which asks for a covariance matrix S using configuration blocks 2, 3, 4, and 5 is the same. However, unlike the MUSIC method, this invention is [0050] by the wait vector W which is the output of a covariance matrix S, and the wait vector selector / search control circuit 9 which count of the characteristic value decomposition / characteristic vector by the characteristic value / characteristic vector count / memory circuit of drawing 2 is not performed, but is an output of 5 to (15) type count circuit 10.

$$|\overline{Y}|^2 = W^H S W \qquad \text{--- (15)}$$

[0051] It calculates. boil a circuit 9 memory 6 -- [0052] which is calculated by the wait calculus-of-vectors circuit 7, and is stored in the wait vector memory 8 from all the stored 0 degree - 360 degrees array manifold data

$$W(\theta_1),\ W(\theta_1, \theta_2), \text{---}, W(\theta_1, \theta_2, \text{---}, \theta_{M-1})$$

[0053] Drawing and a combination search are performed for a ** wait vector. Next, the output of the count circuit 10 is [0054].

$$\left||\overline{Y}|^2 - \sigma^2\|W\|^2\right| \ / \ 10\log 10\left(\frac{1}{\left||\overline{Y}|^2 - \sigma^2\|W\|^2\right|}\right)$$

[0055] It is sent to count / memory circuit 11, and is [0056].

$$\left||\overline{Y}|^2 - \sigma^2\|W\|^2\right|$$

(絶対値をとるのは±の符号は評価上不要のため)

[0057] And it is [0058] for a display.

$$10\log 10\left(\frac{1}{\left||\overline{Y}|^2 - \sigma^2\|W\|^2\right|}\right)$$

[0059] It calculates and stores. It is [0060] by combination search.

$$10\log 10\left(\frac{1}{||\overline{Y}|^2 - \sigma^2\|W\|^2}\right)$$

[0061] theta 1 used as a ** peak, theta 2, --thetaD It becomes the combination of the arrival bearing for which combination asks, and the arrival bearing of the interference wave on which a coherent signal is intermingled can be decomposed and presumed. moreover, the array component and array array of arbitration -- applicable -- the number of the maximum presumption incoming waves -- MUSIC -- law -- being the same (M-1) -- it becomes.
[0062]
[Effect of the Invention] Also in the case of an interference wave including the coherent signal which has perfect correlation in a feeling of an incoming wave, according to this invention, bearing of them can be decomposed and presumed as explained above. Moreover, in the array component of arbitration, and an array array, it can apply, and the bearing measuring device with which the number of incoming waves which can be presumed turns into (the array element

number M-1) can be realized.

[Translation done.]